

Episode 228: The Young modulus

The Young modulus is often regarded as the quintessential material property, and students can learn to measure it. It is a measure of the stiffness of a material; however, in practice, other properties of materials, scientists and engineers are often interested in, such as yield stress, have more influence on the selection of materials for a particular purpose.

Summary

Discussion: Defining the Young modulus. (20 minutes)

Student activity: Studying data. (20 minutes)

Student experiment: Measuring the Young modulus. (60 minutes)

Student experiment: An alternative approach using a cantilever. (30 minutes)

Discussion: Comparing experimental approaches. (10 minutes)

Student questions: Involving the Young modulus. (30 minutes)

Discussion:

Defining the Young modulus

A typical value of k might be 60 N m^{-1} . What does this mean? (60 N will stretch the sample 1 m.) What would happen in practice if you did stretch a sample by 1m? (It will probably snap!)

A measure of stiffness that is *independent* of the particular sample of a substance is the Young modulus E .

Recall other examples you have already met of 'sample independent' properties that only depend upon the substance itself:

- density = mass / volume
- electrical resistivity = (resistance \times area) / length
- specific heating capacity = thermal energy / (mass \times temperature change)
- thermal conductivity = (thermal power \times length) / (area \times temperature difference)

We need to 'correct' k for sample shape and size (i.e. length and surface area).

TAP 228-1: The Young modulus

Note the quantities, symbols and units used:

Quantity	Definition	Symbol	Units
Stress	tension/area = F / A	σ (sigma)	$\text{N m}^{-2} = \text{Pa}$
Strain	extension per original length = $\Delta x / x$	ϵ (epsilon)	no units (because it's a ratio of two lengths)
Young Modulus	stress/strain	E	$\text{N m}^{-2} = \text{Pa}$

Strains can be quoted in several ways: as a %, or decimal. E.g. a 5% strain = 0.05.

TAP 228-2: Hooke's law and the Young modulus

Student activity:

Studying data

It is helpful if students can learn to find their way around tables of material properties. Give your students a table and ask them to find values of the Young modulus. Note that values are often given in GPa ($= 10^9$ Pa).

Some interesting values of E

- DNA $\sim 10^8$ Pa
- spaghetti (dry) $\sim 10^9$ Pa
- cotton thread $\sim 10^{10}$ Pa
- plant cell walls $\sim 10^{11}$ Pa
- carbon fullerene nanotubes $\sim 10^{12}$ Pa

TAP 228-3: Materials database

Student experiment:

Measuring the Young modulus

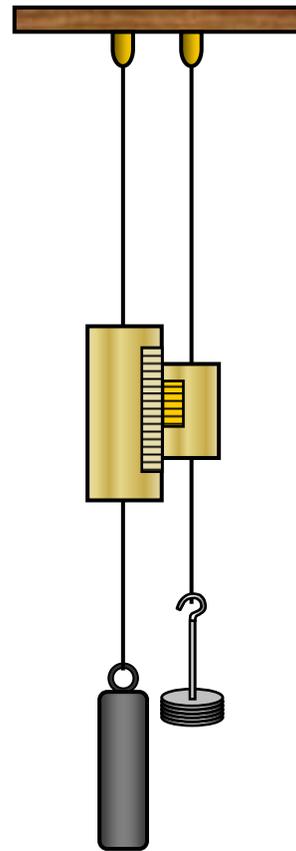
You can make measuring the Young modulus E a more interesting lab exercise than one which simply follows a recipe. Ask students to identify the quantities to be measured, how they might be measured, and so on. At the end, you could show the standard version of this experiment (with Vernier scale etc.) and point out how the problems have been minimized.

What needs to be measured? Look at the definition: we need to measure load (easy), cross-sectional area A , original length x_0 (so make it reasonably long), and extension Δx .

Problems? Original length – what does this correspond to for a particular experimental set up? Cross-sectional area: introduce the use of micrometer and/or vernier callipers. Is the sample uniform? If sample gets longer, won't it get thinner? Extension – won't it be quite small?

Should the sample be arranged vertically or horizontally?

Divide the class up into pairs and brainstorm possible methods of measuring the quantities above, including the pros and cons of their methods.

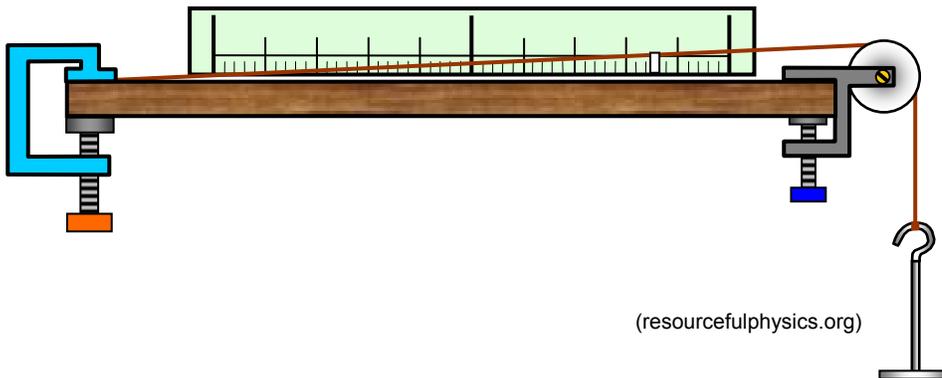


Some possibilities for measuring Δx :

Method	Pros	Cons
attach a pointers to the wire	measures Δx directly	may affect the sample; only moves a small distance
attach a pointer to the load	measures Δx directly, does not effect the sample	only moves a small distance
attach a pulley wheel	'amplifies' the Δx	need to convert angular measure to linear measure, introduces friction
attach a pointer to the pulley wheel	'amplifies' the Δx even more	need to convert angular measure to linear measure, introduces friction
exploit an optical level	a 'frictionless' pointer, 'amplifies' the Δx even more	need to convert angular measure to linear measure, more tricky to setup?
illuminate the pointer etc to produce a magnified shadow of the movement	Easy to see movement	Need to calculate magnification. Can be knocked out of place.
use a lever system to amplify or diminish the load and provide a pointer	useful for more delicate or stiff samples; can use smaller loads	fixing the sample so it doesn't 'slip', need to convert angular measure to linear measure

Different groups could try the different ideas they come up with. Depending upon the time available, it may be worth having some of the ideas already set up.

Give different groups different materials, cut to different sizes, for example: metal wires (copper, manganin, constantan etc), nylon (fishing line), human hair (attach in a loop using Sellotape), rubber.

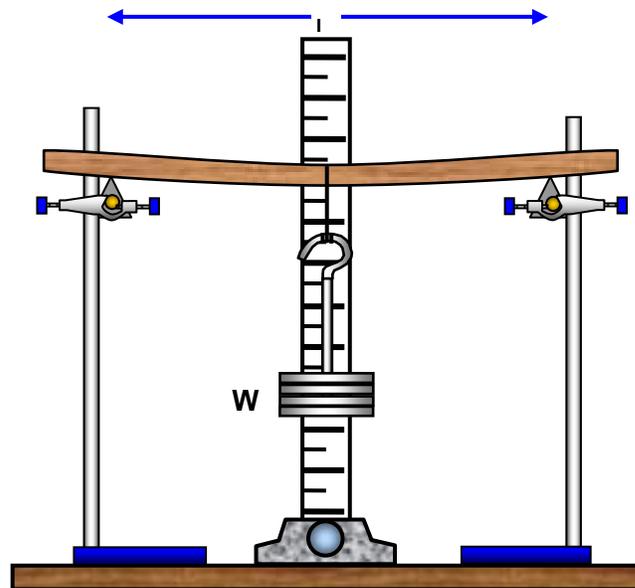


Note that in the set up above, the sample is at an angle to the ruler – a source of systematic error.

Safety

Students should wear eye protection, provide safe landing for the load should sample break, e.g. a box containing old cloth. For the horizontal set up: 'bridges' over the sample to trap the flying ends, should the sample snap.

Good experimental practice: measure extension when adding to the load and when unloading, to check for any plastic behaviour.



(resourcefulphysics.org)

TAP 228-4: Measuring the stiffness of a material

TAP 228-5: Stress–strain graph for mild steel

Information about the use of precision instruments (micrometer screw gauge, Vernier callipers and Vernier microscope).

TAP 228-6: Measure for measure

Student experiment:

An alternative approach using a cantilever

An alternative approach to measuring the Young modulus is to bend a cantilever. (Potential engineering students will benefit greatly from this.)

For samples too stiff to extend easily (e.g. wooden or plastic rulers, spaghetti, glass fibres) the deflection y of a cantilever is often quite easy to measure and is directly related to its Young modulus E .

If the weight of the cantilever itself is mg , and the added load is Mg and L is the length of the cantilever (the distance from where the cantilever is supported to where the load is applied):

<p>For a rectangular cross section, dimension in the direction of the load = d, other dimension = b</p> $y = \frac{4}{E b d^3} (Mg + 5mg/16) L^3$ <p>(for square cross-section $d = b$)</p>	<p>For a circular cross-section radius r</p> $y = \frac{4}{3 \pi r^4 E} (Mg + 5mg/16) L^3$
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Discussion:

Comparing experimental approaches

Finish with a short plenary session to compare the pros and cons of the different experimental approaches.

Student questions:

Involving the Young modulus

Questions involving stress, strain and the Young modulus, including data-handling.

TAP 228-7: Calculations on stress, strain and the Young modulus

TAP 228-8: Stress, strain and the Young modulus

TAP 228- 1: The Young modulus

The Young modulus tells us how a material behaves under stress.

The Young modulus 1

Many materials stretch in a uniform way. Increase the stretching force in equal steps, and the extension increases in equal steps too, in proportion. That is, the strain is proportional to the stress producing it. This is the same as Hooke's law – the stretching of a spring is proportional to the stretching force you apply.

extension 0 x 2x 3x

$\sigma = \frac{F}{A}$

stress σ

strain $\epsilon = \frac{x}{L}$

stress σ

strain ϵ

0 0 ϵ

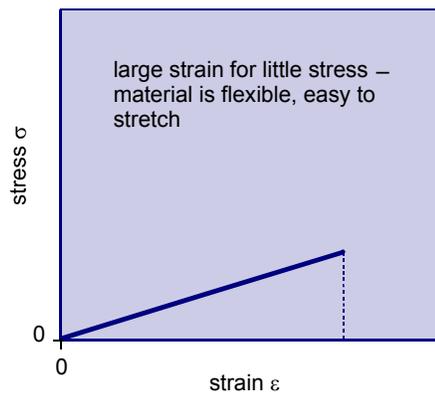
strain \propto stress graph is straight line

ratio $\frac{\text{stress}}{\text{strain}}$ is constant

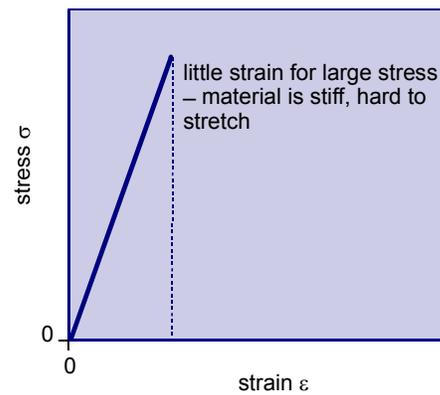
Young modulus = $\frac{\text{stress}}{\text{strain}}$

$E = \frac{\sigma}{\epsilon}$

The Young modulus 2



e.g. polymer



e.g. diamond, steel

The Young modulus is *large* for a stiff material (large stress, small strain). Graph is steep.

The Young modulus is a property of the material not the specimen. Units of the Young modulus MN m^{-2} or MPa; for stiff materials GN m^{-2} or GPa. Same as units of stress, because strain is a ratio of two lengths, e.g. extension is 1% of length

Practical advice

This physics box could be used as an OHT for discussion.

Alternative approaches

The page could be printed out for students to add to their notes for revision.

External references

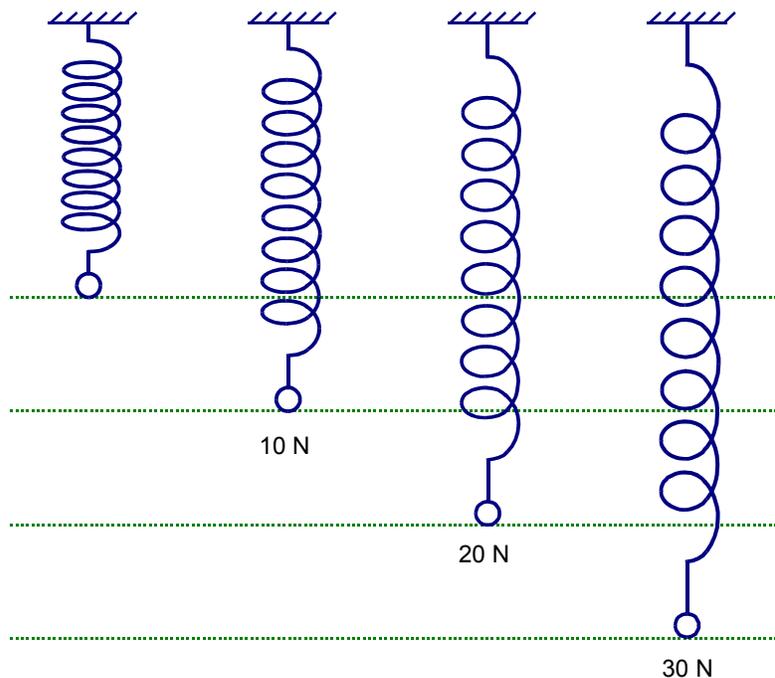
This activity is taken from Advancing Physics Chapter 4, 500

TAP 228- 2: Hooke's law and the Young modulus

Purpose

The Young modulus tells you about what happens when a material is stretched – how stiff is it? You have probably done an experiment to see how stiff a spring is. This reading explains how these two ideas are related.

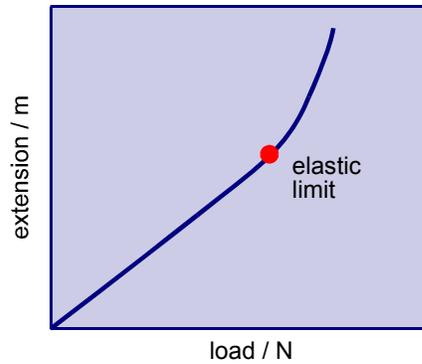
Relating stretching materials to stretching springs



You have probably done an experiment like the one shown here; use a load to stretch a spring, and the increase in length (extension) of the spring is proportional to the load. If a spring (or anything else) behaves like this, with extension proportional to load, we say that it obeys Hooke's law.

At first, if you remove the load, the spring returns to its original length. This is elastic behaviour.

Eventually, the load is so great that the spring becomes permanently deformed. You have passed the elastic limit.



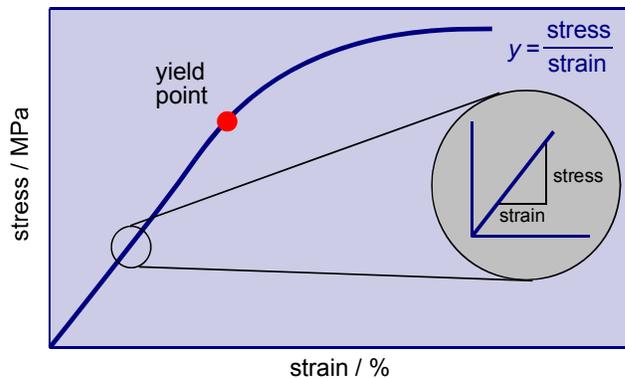
A graph is a good way to show this behaviour, one way is above, but it's usual to plot load on the y-axis and extension on the x-axis so that the spring constant k is measured in Nm^{-1} is the slope of the graph. (For the reason see: TAP 227-2: Tension and extension)

The initial straight-line part of the graph shows that the extension is proportional to the load.

After the elastic limit, the graph is no longer linear. Remove the load, and the spring is permanently stretched.

The initial slope of the load vs. extension graph shows how stiff the spring is – how many Newtons are needed to produce each centimetre (or metre) of extension. This is sometimes called the spring's stiffness or spring constant k .

Now compare this with the stress–strain graph for a copper wire.



The initial straight-line part of the graph shows that the strain is proportional to the stress.

After the elastic limit or yield point, the graph is no longer linear. Remove the load, and the wire is permanently stretched.

From the initial slope of the graph, we can deduce the Young modulus.

The graph will bend the same way to the Hooke's law graph if Tension is on the y-axis and extension on the x-axis. From the definitions of stress and strain, you should see that:

- stress corresponds to load
- strain corresponds to extension

Practical advice

At pre-16 level (or earlier), most students will have carried out a spring-stretching experiment. They may not be familiar with the formal term 'Hooke's law'.

This reading relates the measurement of the Young modulus to Hooke's law; students may need help with the idea of proportionality, and how this can be deduced from a graph.

The reading also considers the non-linear part of the graph. Conventionally, the axes are reversed for the Young modulus graph.

Social and human context

Robert Hooke and Thomas Young are both interesting characters who have far more to them than this relationship.

External references

This activity is taken from Advancing Physics Chapter 4, reading 40S

TAP 228- 3: Materials database

Here are data for about a dozen properties of some 50 materials in Excel spreadsheet format. You can create lists ordered by property, search for materials with properties in certain ranges, etc. To compare pairs of properties, it is best to use the selection charts.

If you double click on the chart below it will open as an Excel spreadsheet that can be copied and used.

	Density / kg m ⁻³	The Young Modulus / GPa	Toughness / J m ⁻²	Elastic Limit / MPa	Energy Content / MJ kg ⁻¹
Cotton	1540	5	400	190	5.7
Leather	920	0.22	67000	3.2	14
Silk	1300	8.7	230	350	7.7
Wool	1300	4.5	440	89	7.7
Al Alloy	2700	77	9300	120	280
Austenitic Stainless Steel	7800	200	8900	410	100
Brass	8200	110	24000	190	110
Cast Iron	7400	130	3400	230	51
Copper	8935	130	32000	120	110
Gold	19300	78	46000	28	5800
High Alloy Steel	8300	240	2000	1600	66
Lead	11350	14	5400	6.9	40
Low Alloy Steel	7850	210	14000	740	71
Mg Alloy	1800	43	5000	170	400

Possible uses of the spreadsheet:

1. Simple reference source for materials data – e.g. to solve quantitative problems involving materials selection, e.g. perhaps calculate the necessary thickness for required thickness or strength of a cantilever.
2. Sort by property, e.g. which are the ten toughest materials in the database?
3. Search with logical operators, e.g. find all materials in the database stiffer than X, stronger than Y, less dense than Z. Try doing this by reading the information from a couple of charts.
4. Explore combinations of material properties not provided as selection charts – e.g. plot modulus against strength. Note that single 'typical' values are provided in the database rather than the full range, so this does give a true selection chart, but can identify interesting trends.
5. Design problems often lead to combinations of properties for which high or low values are required. A common example is 'specific stiffness' (the Young modulus divided by density), which gives an indication of materials which are light and stiff. Specific stiffness and strength are shown in one of the selection charts. Other compound properties for particular design problems could be calculated and plotted using the spreadsheet.

Also provided, below is a data that provides definitions of the materials in the database, and summarises their strengths and weaknesses in engineering design, typical applications and environmental notes. This is a useful reference source for materials. Not all will be needed.

Materials information

Double click on the icon below to access a materials database. This is an html document and will activate internet explorer. It has been virus checked.



040076f1.htm

Practical advice

This database has many potential uses e.g. comparison of experimental values.

Alternative approaches

Data books may be used to augment the information provided here. It has been deliberately provided in an open format.

Social and human context

The ability to search, sort and calculate adds value to raw data.

External References

This activity is taken from Advancing Physics Chapter 4, file 10D

TAP 228- 4: Measuring the stiffness of a material

Stress–strain curves are used to measure stiffness

In this experiment, you will load a wire and record its extension for each load, plotting a graph of the results. From this, you will be able to calculate the Young modulus for the material of the wire. The Young modulus is given by the slope of your graph, and is a measure of the stiffness of the material – for the steeper the gradient, the stiffer (harder to extend) the material.

Collect these to start

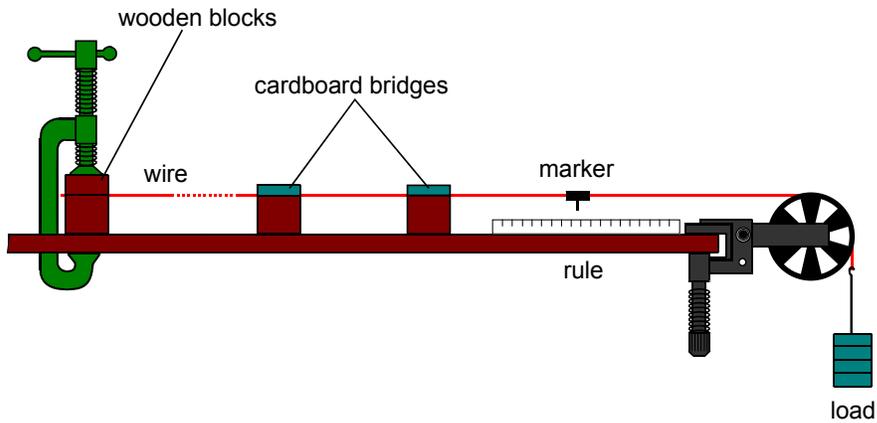
- ✓ G clamp, 10 cm jaw
- ✓ 2 wooden blocks
- ✓ single pulley on a bench clamp
- ✓ metre rule
- ✓ adhesive tape to make marker
- ✓ cardboard bridges
- ✓ mass hanger with slotted masses, 100 g
- ✓ wire samples: 0.08 mm stainless steel, 0.28 mm copper, 0.20 mm iron
- ✓ nylon monofilament, 2 kg breaking strain
- ✓ safety spectacles

	Safety
	<p>The load should not be too high off the floor, and there should be a suitable soft 'landing platform' (not your feet!) if (when) the sample breaks.</p> <p>Use eye protection –beware of the fibre 'whipping back' if it breaks. Do not lean over the stretched fibre.</p> <p>Strained wires store lots of energy. When they break, this is released over a very short time period. It is very important that safety spectacles are worn and that the cardboard bridges are fitted.</p> <p>The cardboard bridges are heavy angled pieces of corrugated cardboard which sit over the wire to prevent it flying back. If cardboard of large mass per square metre is not available then glue wooden blocks to the bottom of less massive card angles and thread the wire through the resulting triangles.</p>

Procedure

This experiment requires you to measure small lengths and small changes in position. Only the simplest technique is given here – you should be able to modify the experiment to produce more valid results.

1. Stretch the wire and fix it horizontally along the bench as shown in the diagram.



2. Make a marker from adhesive tape and attach it to the wire so that it is at least 2 m from the clamp and about 50 cm from the pulley. The marker should line up with the metre rule, so it can be used to measure the extension of the wire. Make a loop in the end of the wire to be loaded, to hang the weights from (a knot will weaken it).
3. Measure and record the original length from the clamp to the marker, with a small (1 N) load to stretch out the wire.
4. Increase the load gradually in steps of 1 N until the wire snaps. Record the load and the corresponding extension in each case.

Calculating the Young modulus

1. Convert your readings of load into stress: ($1 \text{ mm}^2 = 10^{-6} \text{ m}^2$)
Convert the readings of extension into strain: both extension and original length being measured in the same units.
2. Now plot stress (y axis) against strain (x axis).
3. Find the slope of your graph to obtain a value for the Young modulus. Compare it to the value given in the database.

TAP 228-3: Materials database

Practical advice

This version of the tensile testing could be extended to materials such as cotton thread or hair if the diameter could be estimated or measured using a micrometer. Point out features such as necking – the localised narrowing of the wire before fracture – and if time permits, examine the fracture surfaces with a magnifying glass.

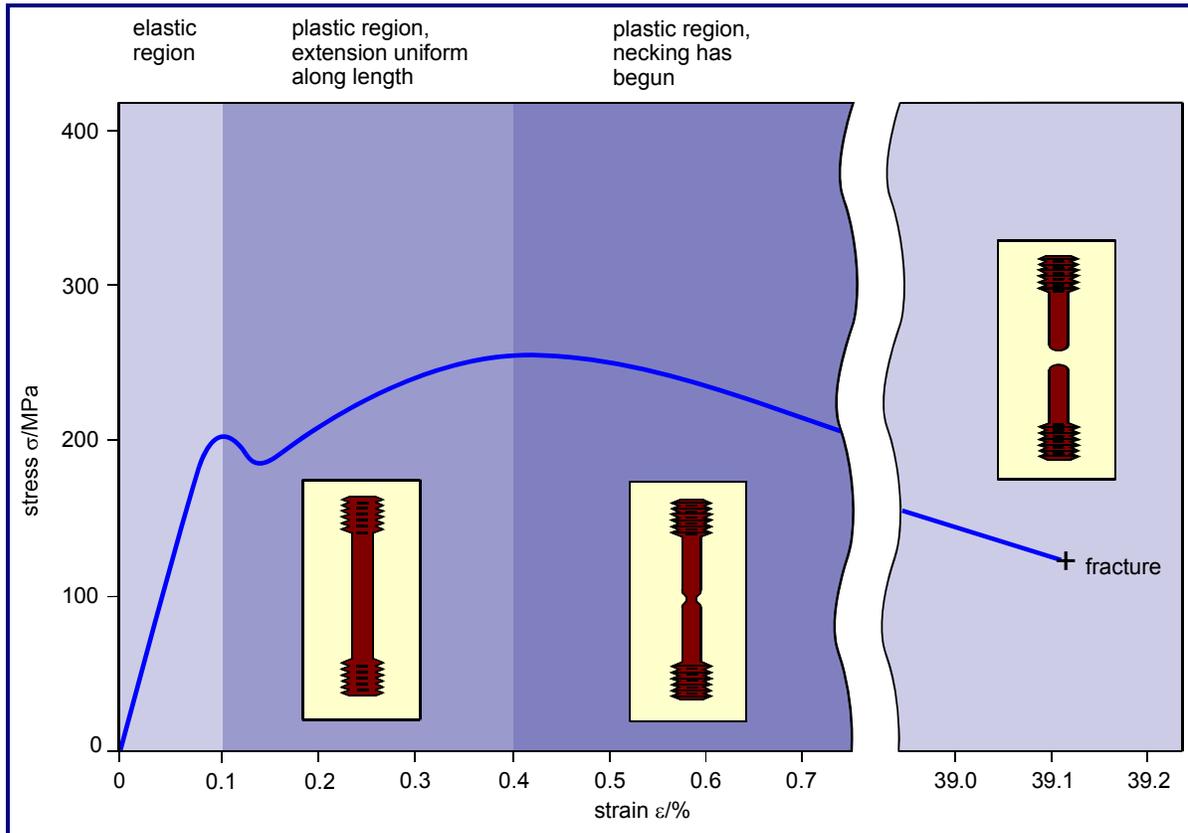
	Safety
	<p>The load should not be too high off the floor, and there should be a suitable soft 'landing platform' (not your feet!) if (when) the sample breaks.</p> <p>Use eye protection –beware of the fibre 'whipping back' if it breaks. Do not lean over the stretched fibre.</p> <p>Strained wires store lots of energy. When they break this is released over a very short time period. It is very important that safety spectacles are worn and that the cardboard bridges are fitted.</p> <p>The cardboard bridges are heavy angled pieces of corrugated cardboard which sit over the wire to prevent it flying back. If cardboard of large mass per square metre is not available then glue wooden blocks to the bottom of less massive card angles and thread the wire through the resulting triangles.</p>

External references

This activity is taken from Advancing Physics Chapter 4, 150E

TAP 228- 5: Stress–strain graph for mild steel

The graph shows how the behaviour of steel changes as the stress increases.



Practical advice

This version could have information added during discussion, for example: -

Mild steel showing elastic behaviour for small extensions, (Hooke's law region), elastic limit, size of strain when fractures (about 40%)

Alternative approaches

The students could have a hard copy of the graph and add the captions for revision of interpreting stress–strain graphs

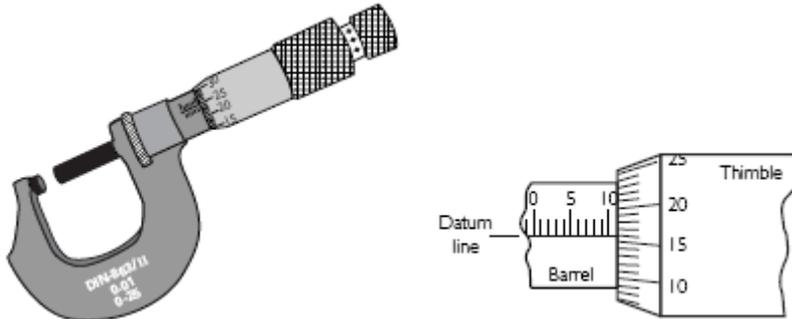
External references

This activity is taken from Advancing Physics Chapter 4, 600

TAP 228- 6: Measure for measure

This sheet shows you how to use some precision measuring instruments.

The diagram below shows a micrometer screw gauge, which enables you to measure small thicknesses to a high degree of precision.



Above: - Micrometer screw gauge and (right) an example reading

The gauge consists of a very accurately threaded screw which, when the thimble is rotated, opens the micrometer's jaws by a precisely known distance. With the most common type, a rotation of the thimble through one revolution opens the jaws by 0.5 mm. The thimble is divided into 50 equal divisions, and so each division represents 0.5 mm/50 or 0.01 mm. The barrel has a datum line graduated in whole millimetres along the top (and some also have half millimetre intervals along the bottom).

Initially screw up the micrometer using its ratchet until its jaws are fully closed. Note the reading on the thimble at the datum line \pm usually this will be zero. If there is a reading apart from zero, then this is the zero error and needs to be recorded and allowed for. Zero errors are noted as + if they are above zero and - if they are below 0. They need to be subtracted from or added to the measured reading.

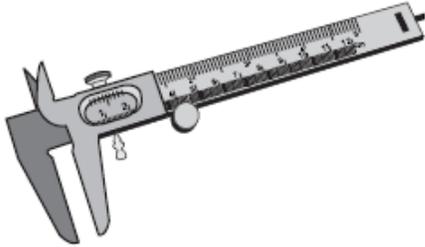
Taking a reading

See the diagram on the right above.

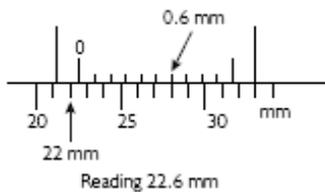
		Reading/mm
Highest number along the datum line	10	10.00
the next line along datum line is not yet uncovered so the final reading is less than 11 mm		
Reading on thimble	16 0	0.16
Uncorrected reading		10.16
Zero error (below zero)	-2	0.02
Corrected reading (add zero error)		10.18

Vernier callipers

The diagram shows callipers that can measure up to several centimetres to the nearest 0.1 mm by making use of a vernier scale. The upper jaws are used to measure distances internally, e.g. the internal bores of pipes. The lower jaws are used to measure distances externally, e.g. diameters of ball bearings.



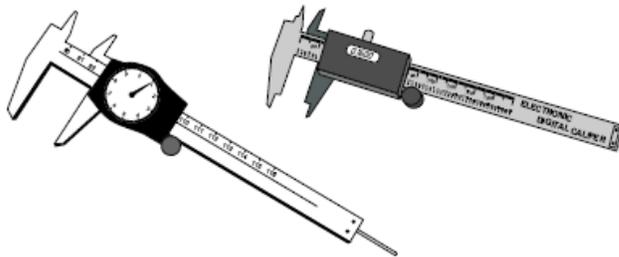
When the zero of the vernier scale is exactly opposite one of the mm marks on the main scale, only its zero mark lines up with a mark on the main scale, and all the others are 'out of kilter'. If the vernier is advanced by exactly 0.1 mm, then the first vernier mark is aligned with a mark on the main scale. If it is advanced by 0.2 mm, then the second vernier mark is aligned, and so on. The vernier scale thus effectively subdivides the main scale into 0.1 mm divisions.



On the part of the scale shown above the zero on the vernier is just beyond the 22 mm mark, so the reading must be 'twenty two point something'. The line of the vernier that exactly matches a graduation on the main scale is the 6, so the vernier must be 0.6 mm beyond the 22 mm mark. Hence the reading is 22.6 mm.

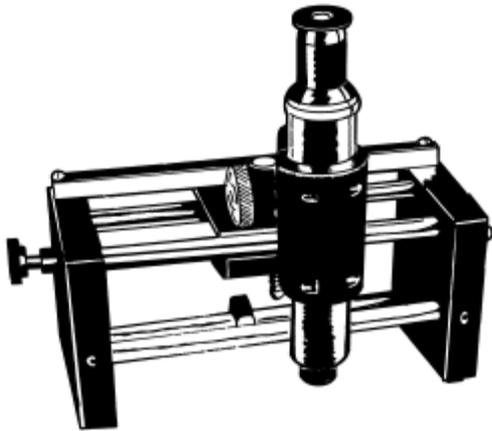
Initially you should close the jaws right up in order to note any zero error that needs to be accounted for. If it reads greater than 0 at this stage, then the reading needs to be subtracted from the final one and vice versa.

There are other types of callipers (below) having dial and digital LCD and LED displays which are, like the digital micrometer, very straightforward to use.



An applet simulation for vernier callipers is available at <http://www.phy.ntnu.edu.tw/java/ruler/vernier.html> (This was available in August 2005)

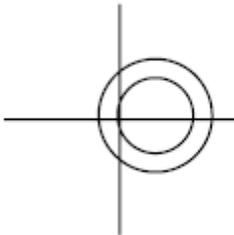
Vernier microscope



A vernier microscope, which can be used to measure distances to the nearest 0.01 mm.

The vernier scale is identical to that of the vernier callipers except that the divisions are 0.01mm instead of 0.1mm and you need to use a magnifying lens to read it.

One use for a vernier microscope is in measuring the internal bore of glass tubing. This is done by moving the microscope carriage on its rack-and-pinion drive by turning the adjusting screw and aligning the cross-wires first on one internal edge of the tube (below) and then on the opposite edge. The bore of the tube is found from the difference between the two readings.



Practical advice

It is useful for students to be able to use a micrometer and a vernier scale. You may choose to show this as part of an activity or have a lesson on use of these devices where the materials for the coming activity are measured.

External references

This activity is taken from Salters Horners Advanced Physics, Section GETE, Additional Sheet 8

TAP 228- 7: Calculations on stress, strain and the Young modulus

Practice questions

These are provided so that you become more confident with the quantities involved, and with the large and small numbers.

Try these

A strip of rubber originally 75 mm long is stretched until it is 100 mm long.

1. What is the tensile strain?
2. Why has the answer no units?
3. The greatest tensile stress which steel of a particular sort can withstand without breaking is about 10^9 N m^{-2} . A wire of cross-sectional area 0.01 mm^2 is made of this steel. What is the greatest force that it can withstand?
4. Find the minimum diameter of an alloy cable, tensile strength 75 MPa, needed to support a load of 15 kN.
5. Calculate the tensile stress in a suspension bridge supporting cable, of diameter of 50 mm, which pulls up on the roadway with a force of 4 kN.
6. Calculate the tensile stress in a nylon fishing line of diameter 0.36 mm which a fish is pulling with a force of 20 N

7. A large crane has a steel lifting cable of diameter 36 mm. The steel used has a Young modulus of 200 GPa. When the crane is used to lift 20 kN, the unstretched cable length is 25.0 m. Calculate the extension of the cable.

Practical Advice

The correct use of quantity algebra will help to remind students to convert mm to m, and similar traps.

Answers and worked solutions

1.

$$\text{strain} = \frac{\text{extension}}{\text{original length}}$$

$$= \frac{25 \text{ mm}}{75 \text{ mm}}$$

$$\text{Strain} = 0.33$$

This is sometimes expressed as a strain of 33%.

2. Strain has mm/mm. These cancel out to give a quantity with no units.

3.

$$\text{stress} = \frac{\text{force}}{\text{area}}$$

$$\text{so } F = \text{stress} \times A$$

$$= 10^9 \text{ N m}^{-2} \times 10^{-8} \text{ m}^2$$

$$F = 10 \text{ N}$$

4.

$$\text{stress} = \frac{\text{force}}{\text{area}}$$

so

$$\text{area} = \frac{\text{force}}{\text{stress}}$$

$$= \frac{15 \text{ kN}}{75 \text{ MN m}^{-2}}$$

$$\text{Area} = 2 \times 10^{-4} \text{ m}^2$$

$$A = \frac{\pi d^2}{4}$$

so

$$d = \sqrt{\frac{\pi d^2}{4}}$$

$$d = \sqrt{\frac{4 \times 2 \times 10^{-4} \text{ m}^2}{3.14}}$$

$$d = 1.6 \times 10^{-2} \text{ m or } 1.6 \text{ cm}$$

5.

$$A = \frac{\pi d^2}{4}$$

$$= \frac{3.14 \times (50 \times 10^{-3} \text{ m})^2}{4}$$

$$= 1.96 \times 10^{-3} \text{ m}^2$$

$$\text{stress} = \frac{\text{force}}{\text{area}}$$

$$= \frac{4 \text{ kN}}{1.96 \times 10^{-3} \text{ m}^2}$$

$$\text{Stress} = 2.0 \times 10^6 \text{ N m}^{-2} \text{ or } 2.0 \text{ MPa}$$

6.

$$A = \frac{\pi d^2}{4}$$

$$= \frac{3.14 \times (0.36 \times 10^{-3} \text{ m})^2}{4}$$

$$= 1.017 \times 10^{-7} \text{ m}^2$$

$$\text{stress} = \frac{\text{force}}{\text{area}}$$

$$= \frac{20 \text{ N}}{1.017 \times 10^{-7} \text{ m}^2}$$

$$\text{Stress} = 200 \text{ MPa}$$

7.

$$A = \frac{\pi d^2}{4}$$

$$= \frac{3.14 \times (3.6 \times 10^{-2} \text{ m})^2}{4}$$

$$= 1.02 \times 10^{-3} \text{ m}^2$$

$$E = \frac{F/A}{\Delta l/l}$$

so

$$\Delta l = \frac{F \times l}{A \times E}$$

$$= \frac{20 \times 10^3 \text{ N} \times 25 \text{ m}}{1.02 \times 10^{-3} \text{ m}^2 \times 2 \times 10^{11} \text{ N m}^{-2}}$$

[ecf answer should be \$2.5 \times 10^{-1} \text{ m}\$ or 25 cm](#)

I make 25mm

$$\Delta l = 2.5 \times 10^{-3} \text{ m or } 2.5 \text{ mm}$$

External References

This activity is taken from Advancing Physics Chapter 4, 45S

TAP 228- 8: Stress, strain and the Young modulus

1. A long strip of rubber whose cross section measures 12 mm by 0.25 mm is pulled with a force of 3.0 N. What is the tensile stress in the rubber?
2. Another strip of rubber originally 90 mm long is stretched until it is 120 mm long. What is the tensile strain?

The marble column in a temple has dimensions 140 mm by 180 mm.

3. What is its cross-sectional area in mm^2 ?
4. Now change each of the initial dimensions to metres – what is the cross-sectional area in m^2 ?
5. If the temple column supports a load of 10 kN, what is the compressive stress, in N m^{-2} ?
6. The column is 5.0 m tall, and is compressed by 0.1 mm. What is the compressive strain when this happens?
7. Use your answers to parts 5 and 6 to calculate the Young modulus for marble.

A 3.0 m length of copper wire of diameter 0.4 mm is suspended from the ceiling. When a 0.5 kg mass is suspended from the bottom of the wire it extends by 0.9 mm.

8. Calculate the strain of the wire.

9. Calculate the stress in the wire.

10. Calculate the value of the Young modulus for copper.

Practical advice

Initially students will need help converting from square mm to square m. They should do simple calculations of stress and strain before attempting to directly calculate the Young modulus of a material.

You might find it useful to ask students to solve problems involving rectangular dimensions or given cross sections before they attempt circular cross sections which have the added hazard of remembering to convert diameters to radii.

Social and human context

You can make up your own questions, using interesting contexts, by consulting a table of values for the Young modulus.

Answers and worked solutions

1.

$$\text{stress} = \frac{\text{load}}{A} = \frac{3 \text{ N}}{12 \times 10^{-3} \text{ mm} \times 0.25 \times 10^{-3} \text{ mm}} = 1 \times 10^6 \text{ Pa}$$

2.

$$\text{strain} = \frac{\text{extension}}{\text{length}} = \frac{120 \text{ mm} - 90 \text{ mm}}{90 \text{ mm}} = 0.33$$

3. $140 \text{ mm} \times 180 \text{ mm} = 25200 \text{ mm}^2$

4. $0.140 \text{ m} \times 0.180 \text{ m} = 0.0252 \text{ m}^2$

5.

$$\frac{10 \text{ kN}}{0.025 \text{ m}^2} = 4.0 \times 10^5 \text{ N m}^{-2}$$

6.

$$\frac{1 \times 10^{-4} \text{ m}}{5.0 \text{ m}} = 2.0 \times 10^{-5}$$

(the units cancel out)

7.

$$E = \frac{\text{stress}}{\text{strain}} = \frac{4.0 \times 10^5 \text{ Pa}}{2.0 \times 10^{-5}} = 2 \times 10^{10} \text{ Pa}$$

8.

$$\text{strain} = \frac{\text{extension}}{\text{length}} = \frac{0.9 \times 10^{-3} \text{ m}}{3.0 \text{ m}} = 3.0 \times 10^{-4}$$

9.

$$\text{stress} = \frac{\text{load}}{\text{cross sectional area}} = \frac{5.0 \text{ N}}{\pi(0.2 \times 10^{-3} \text{ m})^2} = 4.0 \times 10^7 \text{ Pa}$$

10.

$$E = \frac{\text{stress}}{\text{strain}} = \frac{4.0 \times 10^7 \text{ Pa}}{3.0 \times 10^{-4}} = 1.3 \times 10^{11} \text{ Pa}$$

External References

This activity is taken from Advancing Physics Chapter 4, 50D